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Long-endurance oceanographic sampling platforms such as gliders and profiling floats provide a new opportunity for acquiring acoustic signals from marine animals with immediate applications in conservation and mitigation. Our objective is to produce a reliable system for persistent passive acoustic monitoring of marine animals. The system, comprising both low-power hardware and acoustic processing software, will be extensible and can be incorporated in a variety of autonomous platforms. The design will be open and available for other researchers to adapt and extend.

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Beta testing of persistent passive acoustic monitors

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LONG-TERM GOALS

Long-endurance oceanographic sampling platforms such as gliders and profiling floats provide a new opportunity for acquiring acoustic signals from marine animals with immediate applications in conservation and mitigation. Our objective was to produce a reliable system for persistent passive acoustic monitoring of marine animals. The system, comprising both low-power hardware and acoustic processing software, will be extensible and can be incorporated in a variety of autonomous platforms. The design will be open and available for other researchers to adapt and extend.

OBJECTIVES

1. Produce 20 DMON digital acoustic monitors for distribution to a group of beta test collaborators. These will be researchers developing systems for acoustic monitoring of marine mammals able to evaluate the device and its software in a range of applications.
2. Support the beta testers with software, hardware and user information.
3. Continue to develop the DMON and its interface with persistent survey platforms. Standardize the user interface to the device using existing open source acoustic monitoring software.

APPROACH

Passive acoustic monitoring (PAM) is used increasingly for detecting the presence and abundance of marine mammals with both scientific and mitigation applications (Mellinger & Barlow 2003; Barlow & Gisiner 2006; Zimmer et al., 2008; Marques et al., 2009). The usual PAM system comprises a mooring which records sound continuously to a hard-drive over several months. The mooring is retrieved periodically at which time the acoustic recording is examined for vocalizations. The 2007-2009 ONR-funded AMT program focused on expanding this technique in two ways. The first goal was to combine acoustic monitoring with mobile oceanographic platforms such as gliders and profiling floats to monitor marine mammal vocalizations and oceanographic conditions over spatial scales of tens to thousands of kilometers (Baumgartner and Fratantoni, 2008). The second focus area was on automatic detection and classification within the PAM device. The capability to process acoustic data on-board autonomous platforms and report detections to ship or shore will greatly increase the efficiency of PAM operations and enable adaptive surveys and real-time monitoring.

Under the AMT program, we developed a small self-contained instrument for real-time detection and classification of marine mammal vocalizations suitable for use on autonomous platforms. The device, called the DMON, monitors up to three hydrophone channels and records sound to solid-state memory either continuously or when a detection is made. The on-board processor is capable of running multiple

detection and classification algorithms simultaneously. Input channels can be configured for wide-band (blue whale to porpoise) monitoring or for direction finding of signals in a narrower band.

Compared to off-the-shelf computer hardware, the DMON offers several advantages:

1. power consumption is <10% of a PC-based solution. This translates into longer deployments on platforms such as gliders with limited hotel load.
2. the DMON is specifically designed for low noise sound acquisition enhancing its capability to detect weak signals from distant animals.
3. the DMON is much smaller than an off-the-shelf solution making it straightforward to install in a variety of platforms.

Disadvantages of custom devices like the DMON are their complex non-portable software and lack of availability to other researchers. The current project addresses these issues by making a pool of devices available to researchers to install in their own platforms. The devices are supported by a well-documented software infrastructure. Our vision is that the DMON form a reference design for the rapidly expanding field of passive acoustic monitoring.

In the current project, we built a set of 20 DMONs packaged for stand-alone use and for inclusion in gliders and profiling floats. Five of the DMONs were to remain at Woods Hole for continued development of detection / classification algorithms and for field testing. The remaining 15 units form a loan-out library to allow evaluation of the device within the broader PAM community. We have identified a set of beta test partners who were interested in customizing DMONs for their applications (e.g., by writing software, adapting hardware, and by interfacing the device to other systems) and were prepared to evaluate the device within their existing field studies. We provided support for these beta-testers with technical assistance, software modifications and documentation. In parallel, we continued our work to characterize and extend the performance of the DMON by bench-testing, calibrating, and field use within other programs. Two specific focus areas for software design in this, and a companion effort (P.I. D. Fratantoni) were platform interface and real-time detection algorithms.

The DMON has been integrated into two persistent monitoring platforms: the Webb Research Corporation's (WRC) Slocum glider and Apex profiling float. External hydrophones for both platforms provide 10Hz-60kHz monitoring. Serial communications with the vehicle controllers allow feedback of detections via Iridium. A drifting surface float with a cabled array of DMONs has also been developed to facilitate field evaluation of detection and tracking algorithms. The three platforms provide the capability to work over a wide range of spatial and temporal scales. Hardware and software integration of the DMONs in these platforms is being performed primarily within the companion effort. Extension to other platforms and some field testing is included in the current project.

We are continuing to develop real-time DMON detection and classification software for baleen whale calls and beaked whale clicks taking advantage of extensive sound data holdings at WHOI. The baleen whale detector involves pitch tracking followed by attribute extraction and classification by quadratic discriminant function analysis. The beaked whale detector incorporates click classification based on spectral and duration cues. In a related project, we are evaluating the detection range of the beaked whale detector using DMON sound recordings of whales tagged with DTAG acoustic recording tags (Johnson & Tyack, 2003).

WORK COMPLETED

Export licensing: As originally planned, the beta-test program included researchers both within and outside of the USA reflecting the international nature of the marine mammal DCL community. We had

planned for an open-hardware / open-software design, the goal being a readily-available reference design which would foster performance comparisons and accelerate the acceptance of persistent passive acoustic monitoring. However, upon requesting a commodity jurisdiction in 2009, the DMON was placed on the US Munitions List and as such is administered under ITAR (International Traffic in Arms Regulations). The result is an export restricted device which considerably limits its attractiveness and ultimately use by foreign collaborators. This required us to somewhat redefine our priorities.

Ultimately, we were able to obtain two licenses in 2010 which allowed us to satisfy most of our prior commitments. The first enabled us to hand carry DMON's into specific countries (notably Canary Islands, Spain) where we were able to deploy DMON's for instrument testing and detection algorithm development. The second was actually a pair of licenses enabling the sale and export of DMON hardware and software to the NATO Undersea Research Center in Italy.

Going forward (late 2010-2011) we had planned the following:

1. Obtain hand-carry licenses for additional countries.
2. Specify a version of the DMON (DMON-Export) which is not export restricted.
3. Identify potential collaborators at foreign universities

Additional hand-carry licenses: In 2011 we obtained 2 new hand-carry licenses. These cover potential operations in Canada and current operations in Australia. We are currently putting together an application for hand-carries to: France, Greece, Iceland, UK, Norway. The goal is to promote work in those areas.

DMON-Export: In an effort to simplify working with foreign collaborators we determined to obtain commodity jurisdiction (CJ) on the DMON-Export, a non-export restricted version of the DMON. To describe a non-export restricted version of the DMON, we first needed to determine what specifications required modification. For this, we worked very closely with Richard M. Ead (Sensors and Sonar Systems Department, Naval Undersea Warfare Center, NUWC Code 1535), Ted Ioannides (PS 4013) and Dave Sebastian.

Paramount to defining the DMON-Export specifications was a calibration of the device at NUWC, Newport. Starting in late 2010 and extending into 2011, we prepared two DMON's and modified them to work with NUWC's calibration facilities. We performed tests in two facilities: System K of the Low Frequency Facility (LOFAC) and the Acoustic Pressure Tank Facility (APTF). These tests were done over the course of a single day (with a separate day of test design and setup) and covered a frequency range of 1 Hz to 40 kHz. All frequencies were tested at the following pressures: ambient, 100 psi, 220 psi and 350 psi. The results would largely shape the acoustics parameters of the DMON-Export. (please see figures 4,5 and 6)

For the new CJ application the following changes were advised:

- Built-in 2-pole high pass filter at 500 Hz on all audio channels
- No external timing-synchronization capability
- No user programming capability
- Modified depth rating (800 m)

These changes were incorporated into a modified set of DMON specifications which provided the basis of a new CJ. In August 2011 we received a favorable decision on DDTC Case CJ 681-11. The determination was that the DMON-Export is not subject to the licensing jurisdiction of the Department of State. The Department of Commerce advises the item be given an Export Control Classification Number of 6A991.

Moving forward with DMON-Export: In August 2012, we completed DMON-Export hardware and firmware modifications to comply with the terms of the Commodity Jurisdiction. DMON-Export units will thus be allowed to operate outside of US territorial waters and by non-US citizens without an export license. As specified in the Commodity Jurisdiction, the modifications prevent reprogramming with non-export firmware, prevent hardware synchronizations of multiple DMONs, mute the audio input below 800m depth, limit recordings to 30 days, limit sampling rates to 160kHz, and digitally filter out audio waveform information below 500Hz.

The first deployment of the DMON-Export will be in October 2012, on an autonomous glider launched from the icebreaker USCGC Healy in the Arctic Ocean. DMON-Export recordings from this deployment will support development of a long-range communication and navigation system allowing under-ice operation of gliders. The first deployment is funded by a WHOI internal award ("Glider Observation of the Western Arctic Boundary Current", PIs D.Gong, L.Freitag, R.Pickart).

Beta-Test Program: The original plan was to build 20 DMONs to be dispersed amongst a select group of collaborators, providing support as necessary. (please see table 1) Each client has received 1-3 DMONs in one of two form factors: (i) a board set ready for installation in a vehicle (Fig. 1), or (ii) a stand-alone instrument (bottle) ready to be deployed at sea (Fig. 2). Each DMON has three independent sound acquisition channels and clients elected whether these were configured for LF (10-8kHz), MF (100-60kHz) or HF (1k-150kHz) operation. The stand-alone instrument contains 3 hydrophones and is capable of operation at up to 2000 meters depth. The board-set option is intended for bench test evaluation, code development and integration into gliders, AUVs or profiling floats. A simple but robust host interface serves as a platform-independent means to upload data and download programs to DMONs. At present we have 19 bottles and 8 card sets built and functional; currently 15 of the bottles and 6 of the board sets are out with customers.

While operations vary, work has ranged from deploying DMON bottles on existing moorings to vehicle integrations. Notable deployments include: (please see table 1 for complete list)

Vehicle Integrations: Throughout 2010 and 2011, we worked closely with Duke University and iRobot Corporation to integrate a DMON onto a seaglider. This included a trip to Durham to meet with the iRobot engineering team and finalize both the hardware and software interfaces. This work was similar to the work integrating a DMON onto the Teledyne/Webb gliders and profilers. (AMT program) The DMON provided acoustic data and communicated some predetermined information (some subset of the data, ie: detections) to the seaglider. The seaglider then passed that data to the shore via iridium link. This system was deployed successfully in Cape Hatteras. iRobot also presented this system at the AUVSI Unmanned System show in Washington, August 2011. (please see figure 7)

In 2012 we sold a DMON to Bruce Howe at the University of Hawaii to integrate into their iRobot seaglider and continue to provide both hardware and software support in conjunction with Duke University.

Brian Bingham and Bruce Howe have also integrated a DMON onto the Liquid Robotics waveglider (2010-2011). For this work, we provided a card set and a pair of hydrophones which were integrated onto the vehicle and deployed in Hawaii. (see figure 10.) Results were reported by Bingham, et al. in The Journal of Field Robotics. (DOI: 10.1002/rob.21424, 2012)

Gerald D'Spain deployed a DMON bottle on the fixed wing ZRay glider during the SCORE range validation testing in January 2011. (please see figure 8) Also present during these tests, David Fratantoni

deployed two custom outfitted Apex Profilers and one Slocum Glider running beaked whale detector code. (more on this in the results section)

Eric Sorenson has been working with Oregon State University to integrate a DMON onto a Teledyne-Webb Slocum glider. We've provided support for ongoing custom hydrophone designs and DMON integration.

Over the Summer of 2012 we worked with Mike Purcell (Engineer, WHOI) and Jennifer Batryn (summer student, WHOI) to integrate a DMON onto a REMUS-100 vehicle. The goal of this work was to characterize the acoustic self-noise and assess the REMUS-100 as a platform for passive marine mammal monitoring. A number of trials were performed in Buzzards Bay (please see figure 11) and the basic conclusion was that the REMUS-100 would be suitable for monitoring above 2kHz but would need modifications to monitor below that.

Moored Operations: We've been talking with scientists throughout WHOI looking to identify suitable applications for the DMON. Throughout 2011 and 2012 we've worked closely with T. Aran Mooney and Laela Sayigh on a number of such applications. (please see figure 13) These include: (1) Passive acoustic monitoring at the first US windfarm site via a mid-water column suspended DMON moored in specific locations. The goal is to characterize overall local soundscapes and measure transmission loss around the windfarm site. DMON's are currently deployed in Nantucket Sound. (2) We are developing and employing a DMON-towfish which is used in combination with a (3) DMON-drifter. Together, the towfish and drifter packages record far-field acoustic data of focal species in concert with concurrent DTAG data collection. The goal is compare DMON recordings to the tag acoustic behavior records to facilitate acoustic analyses of signal classification. We plan to integrate these signal parameters into specific detector and classifier algorithms onboard the DMON. The towfish and drifter were deployed off the coast of Hawaii in August 2012. (4) Finally, we are using a DMON suspended from a kayak and a similar mooring to record sounds of Canadian Cunningham belugas to classify these signals and relate beluga bioacoustics to physical parameters in the local environment. Deployments began in August 2012 and will continue through September 2012.

In 2011 and into 2012 we worked with David Wiley and Danielle Cholewiak on two programs; (1) evaluation of delphinid occurrence in Stellwagen Bank National Marine Sanctuary along with a comparison of autonomous recording platforms and (2) characterization of cod (*Gadus morhua)* acoustic activity. The cod study is interested in determining whether passive acoustics is feasible for spawning habitat surveys. In May 2012 and mini-array was constructed and deployed in the Spring Cod Conservation Zone off the coast of northeast Massachusetts. The array contained three fixed DMON's mounted to a small metal frame. The data will be used to localize vocalizing cod in an effort to inform ongoing studies by the Massachusetts Department of Marine Fisheries on the status of cod spawning stocks in MA waters.

Peter Tyack and Ann Allen (PhD student) deployed a DMON off the coast of Australia primarily looking at surf zone noise. This work required custom low sampling code to be written primarily to lengthen deployment times. Mark Baumgartner stepped in and wrote code to sample a single channel at 16 kHz thus enabling roughly two weeks of continuous data storage. DMON's with this code were deployed between August and September of 2011. This work starts to address one of the main issues we've been looking into: longer duration deployments. While the DMON is ideally suited for integration onto gliders, profilers and moorings many of those platforms are geared toward longer duration experiments. With the low sampling code and internal battery the DMON can accommodate 2 weeks of operation, so to move forward to month or longer deployments we need to address not only storage capacity but also battery capacity.

While no deployments were actually made, we supplied IFAW (International Fund for Animal Welfare) with a DMON to place in Wellfleet Harbor. (Wellfleet, MA) The ultimate goal is to develop a system to alert IFAW to potential stranding events. This would combine a DMON running detection code with a real-time link to shore. We are currently working on funding to develop this system.

RESULTS (SCORE RANGE TESTING)

With the goal being a move toward persistent monitoring with active, real-time detection, the most tangible results for the DMON thus far are from the SCORE range validation testing this past January. As indicated earlier, 2 APEX profilers and 1 Slocum glider were operated and deployed by David Fratantoni, WHOI. These vehicles were the result of a collaboration between WHOI and Teledyne Webb Research, as stated earlier this work was supported by the AMT program. They represent a custom acoustics integration where the DMON electronics hardware was mounted inside the vehicle dry space and wired to its controller. (see figure 9) Code was developed to enable two-way communication between the two devices. In addition, a custom hydrophone array was designed and built for each platform. The beaked detector code, running on all 3 vehicles, was largely the result of field testing in the Canary Islands in 2008-2010.

The Canary Islands involved DMON deployments as part of a NOPP beaked whale habitat and acoustic detection study (see report by Johnson et al.). DMONs were deployed with software for continuous LF and MF sound recording with loss-less compression, timing acquisition from GPS, and real-time beaked whale detection, all operating simultaneously. DMONs were mounted on cables suspended from drifting buoys placed about 1.5 km apart in 1000m water depth. Each buoy supported a DMON at 20m and 200m depth to mimic the normal deployment depths of towed arrays and sonobuoys. Continuous visual coverage of the deployment area was maintained from a shore station equipped with high power binoculars to compare visual and acoustic detections. The DMON click detector reports the quality of each detection in three categories (Class 1-3) along with additional parameters such as processing gain, SNR and transient duration to help classify transients. Some 550,000 clicks, classified as having a high probability of being produced by a beaked whale (i.e., Class 1) were detected by the 4 DMONs during the experiment. The waveforms of a random subset of 15000 detections were checked to establish the miss-classification rate and to determine what types of non-beaked whale signals tended to confound the detector (Fig. 3). This has led to the adoption of improved classification thresholds in the detector. The large click data-set is being used in a companion NOPP project to evaluate detection rate as a function of range and depth.

The Canary Islands data was used to perfect the beaked whale detector code, the SCORE range testing was the first full-up field test of a DMON on a vehicle running real-time detections. (please see figure 14 for block diagram of system)

While more work needs to go into the SCORE data (primarily a more exhaustive analysis and comparison against other designs) the DMON real-time detector and classifier provides a robust first cut of possible beaked whale detections and is efficient at rejecting interfering transient sources.

Following are the summary results:

- Whitening filter optimized for ambient noise in Canary Islands; very little improvement when optimizing for SCORE
- SCORE beaked whale clicks were varied in spectrum (different species, size class, genders?) improved matched filter or filter bank may improve performance

- Glider and Profiler motors and pumps are noisy, however duty cycle of noise is low. Therefore they are viable platforms for persistent detection.
- Profilers were particularly effective, glider less effective due to shallow, short dives.

FUTURE WORK / DEVELOPMENT

We have presented the DMON in a number of venues, notably the 5th International DCLDE workshop in Oregon, August 2011, the 19th Biennial Conference on the Biology of Marine Mammals in Tampa, November 2011 and the ONR review, April 2012. We've also supported many types of applications throughout the Beta Test program, allowing the device to be tested on vehicles, moorings, towfish and drifters. The device has deployed as both a simple continuous recorder and as a real-time detector. After numerous conversations with colleagues we can conclude that the strength of the DMON is its flexibility and utility and the weakness is the duration of its deployments.

It is evident that the DMON program (as well as passive monitoring) would benefit from longer duration deployments. While ultimately systems capable of transmitting real-time detections (possibly storing extracts) are the goal, continuous recordings with post-processing capability remains the norm. One main goal for future development is to add long term capability to the DMON.

To accommodate long deployments, from a power supply perspective, an external battery input was implemented in the DMON. This input is suitable for sub-month long deployments but needs to be redesigned for anything longer. Our current setup is at best 70% efficient, a number that is largely the result of charging the internal battery in addition to powering the DMON. Nevertheless, it needs to be increased to be more energy efficient and minimize battery pack sizes. We are currently looking at re-designing the external battery input with the goal of getting the efficiencies up into the 80-90% region. From a memory perspective, we are looking to increase onboard flash to accommodate 3-6 months of continuous recording.

DMONs have been used in a number of field experiments over the past two years. However, tangible results are limited as many customers are either evaluating monitoring platforms (ie: vehicle self-noise), have yet to analyze sound data or have been in some way unable to deploy a DMON. We've continued to work with customers to evaluate field performance in an effort to further eliminate failure modes, hardware limitations and software bugs. Beta-test colleagues continue to be primarily positive in their assessments; however there are a small number of modifications and additions that we would like to implement. This program has provided a wonderful opportunity to further develop, test and promote the DMON as a viable solution for Passive Acoustic Monitoring. We hope to continue in this endeavor and hope interest in the device continues to grow.

IMPACT/APPLICATIONS

National Security

Concern about potential impacts on acoustically-sensitive cetaceans has constrained some Navy training exercises and has led to lengthy court proceedings. The development of reliable methods to predict and verify the presence of cetaceans will provide the Navy with new tools to help balance preparedness with environmental stewardship.

Economic Development

Economic development brings increasing noise to the ocean from ship traffic and oil exploration. An improved understanding of the abundance and habitat of marine mammals and their use of sound will help to make economic growth sustainable.

Quality of Life

The techniques developed here will lead to improved information about the location and abundance of marine mammals. These results will facilitate improved regional management with implications on ecosystem health.

Science Education and Communication

To the extent possible within export restrictions, we have adopted an open-source approach whereby all aspects of the technology will be available to other researchers. Our goal in doing this is to foster community development of the device and to facilitate the availability of extensible systems for marine mammal acoustics research and training.

TRANSITIONS

DMON devices and technology have been transferred to researchers at NOAA, Scripps Institute of Oceanography and several universities. A subset of the technology has been exported to the NATO Undersea Research Center.

RELATED PROJECTS

D-MONs are being evaluated in several related programs including an NOPP project (P.I. M. Johnson) and the AMT program that was the predecessor of the project reported here (P.I. D. Fratantoni). Other no-cost opportunities to field DMONs are being taken wherever possible to increase information about the performance and limitations of this device.

Funding from SERDP (CS-1188) in 2010 supported the development of a new generation marine mammal tag (DTAG V3). This devices shares many software and hardware features with the DMON and there is considerable synergy between these projects.

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Marques TA, Thomas L, Ward J, DiMarzio N, Tyack PL (2009) Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales. J Acoust Soc Am 125:1982-1994

Mellinger D, Barlow J (2003) Future directions for acoustic marine mammal surveys: Stock assessment and habitat use. NOAA OAR Special Report, NOAA/PMEL Contribution No. 2557, 37 pp. USA

Zimmer WMX, Harwood J, Tyack PL, Johnson M, Madsen PT (2008) Passive acoustic detection of deep diving beaked whales. J Acoust Soc Am 124:2823-2832

Table 1: DMON Beta-Test group

Contact	Affiliation	Application
Gerald D'Spain	SIO	ZRAY glider integration
Aaron Thode	SIO	moorings, code development
Mellinger / Klinck	Oregon State University	moorings, autonomous boat gliders and code development
Siderius / Sorenson	Pennsylvania State University	working with OSU, iRobot seaglider Slocum glider
Madsen / Wahlberg*	Aarhus University	drifting arrays
Walter Zimmer*	NATO Undersea Research Center	towed / drifting array
Susan Parks	Pennsylvania State University	Moorings
David Wiley	Stellwagen Banks National Marine Sanctuary	drifting arrays / moorings humpback whales
DanielleCholewiak	NE Fisheries, Woods Hole	Cod acoustic characterization
Fratantoni / Baumgartner	WHOI	Slocum glider / APEX profilers SCORE range 2011 deployment
Doug Nowacek	Duke University	Seaglider
Edison Hudson	iRobot	Seaglider (with Duke)
Andy Read	Duke University	fishing gear / moorings beaked whales and dolphins
Oleson	NOAA	fishing gear
Whitlow Au	University of Hawaii	moorings / drifting arrays
Wiggins / Hildebrand	SIO	moorings
Matsumoto	NOAA	moorings, bottom seismometry
Howe / Bingham	University of Hawaii	Liquid Robotics waveglider / iRobot seaglider
Adam Frankel	Marine Acoustics, Inc / U of Hawaii	
Dave Johnston	Duke University	
Castellote / Garner	NOAA/Alaska Fisheries	Beluga whale detection and monitoring
Aguilar De Soto / Johnson	U of Auckland / WHOI / Univ. St. Andrews	Abundance surveys Pilot and beaked whales
Tyack / Allen	WHOI	Moored, surf zone noise and acoustics
T Aran Mooney	WHOI	Moored / towed array False killer and melon-headed whales
Purcell / Batryn	WHOI	REMUS self-noise testing

* = specially licensed work with non-US person.

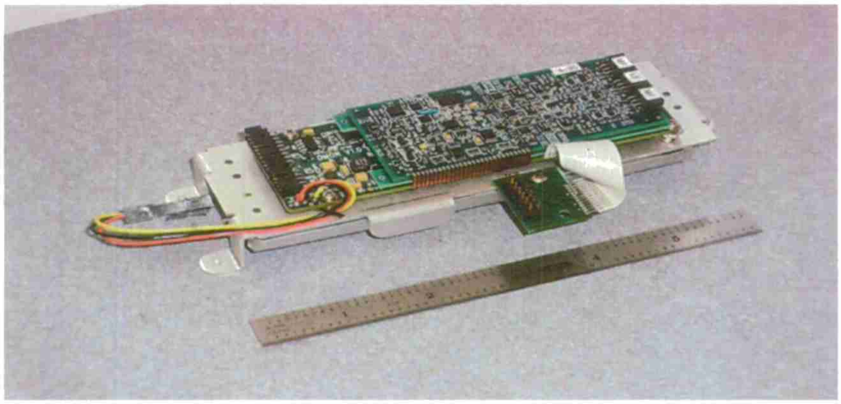


Fig. 1: DMON board set in glider-ready format
The DMON is a set of two circuit boards capable of wide bandwidth acoustic recording and real-time detection. The device consumes little power making it ideal for low hotel load autonomous vehicles like gliders. The format shown here was provided to beta-test clients working on gliders and AUVs.

Fig. 2: DMON in stand-alone configuration
The DMON circuit is pressure tolerant and can be packaged in a low-cost oil-filled housing to minimize acoustic reflections and payload weight. This package was provided to beta-test clients interested in mooring applications or in installi the DMON in the wet-space of a vehicle.

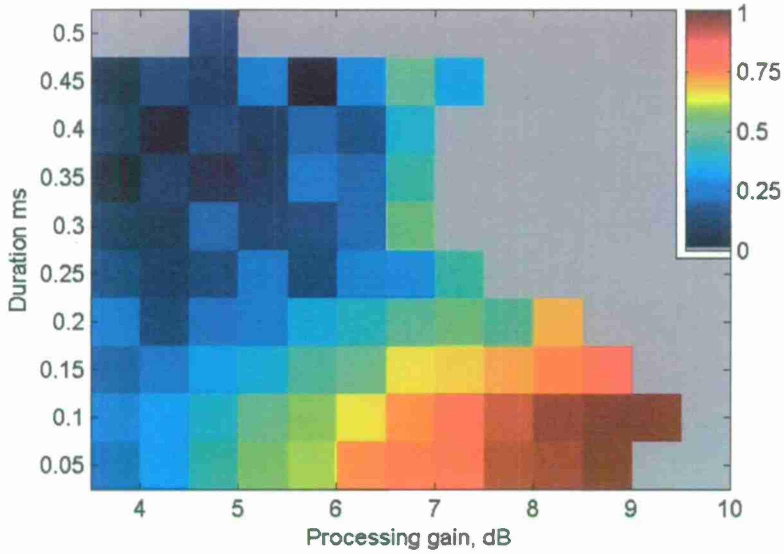


Fig. 3: Field verification of the DMON beaked whale detector in the Canary Islands.
Shown is the proportion of detections considered in post-evaluation to represent an actual beaked whale click, as a function of two click parameters, energy duration and processing gain. Grey regions indicate parameter combinations for which no clicks were received. This plot helps determine how to set parameter thresholds for beaked whale classification. For example, choosing a processing gain threshold of 4+10*duration (in ms) eliminates many false detections.

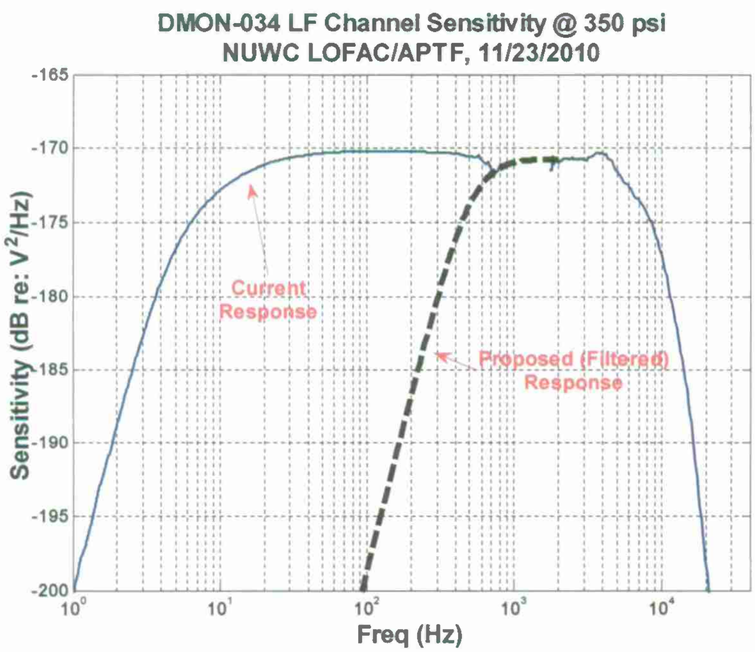


Figure 4: DMON Sensitivity
Calibration at NUWC facility, Winter 2010-2011

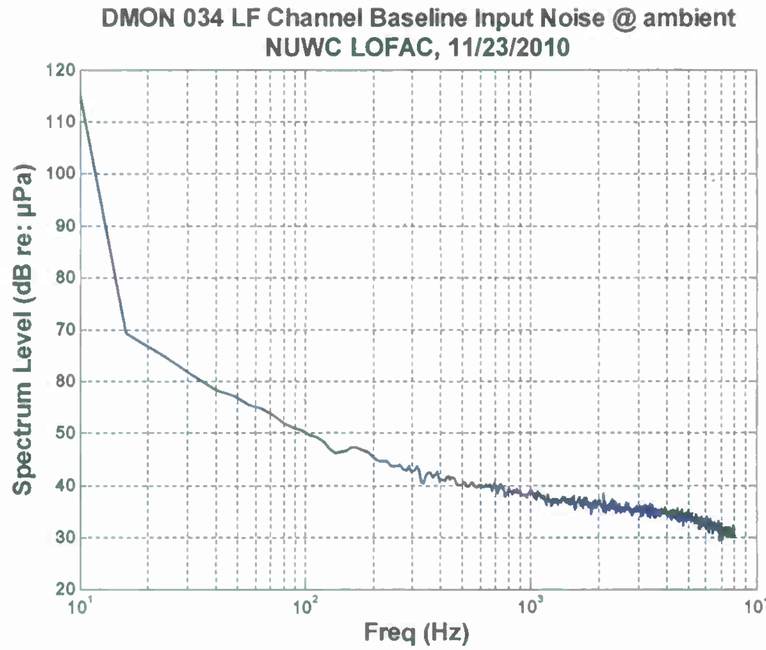


Figure 5: DMON Noise
Calibration at NUWC facility, Winter 2010-2011

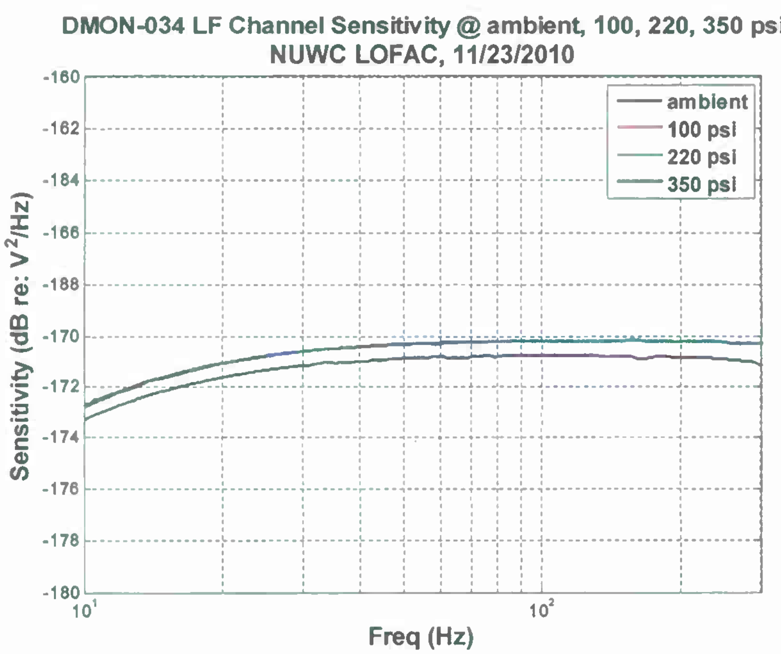


Figure 6: DMON Sensitivity at Depth
Calibration at NUWC facility, Winter 2010-2011

Figure 7: DMON on an iRobot Seaglider
(Shown in tank at AUVSI show in Washington DC)

Figure 8: DMON on ZRay Glider
(ready for SCORE deployment)

Figure 9: DMON custom integration onto Teledyne Webb glider and profiler

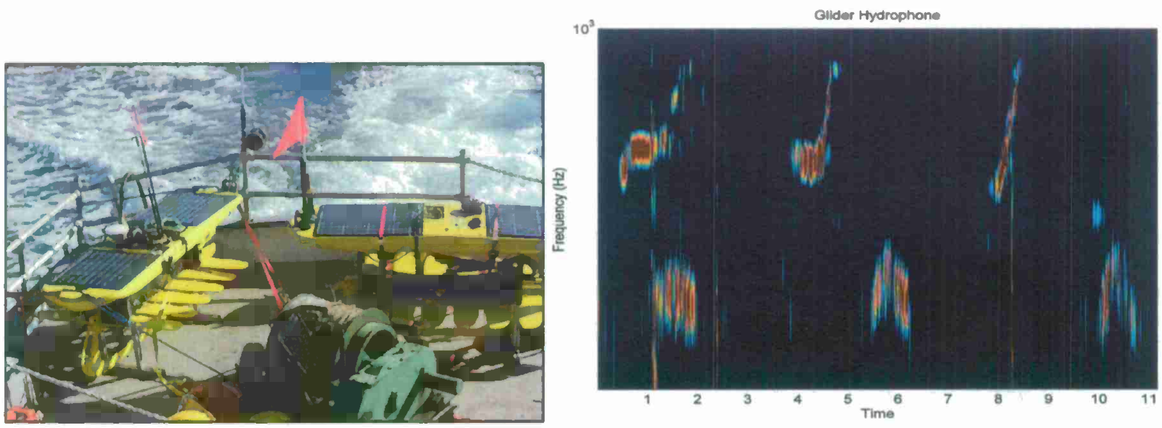


Figure 10: DMON on Liquid Robotics waveglider.
(left), Brian Bingham, U of Hawaii, mounted DMON onto glider and (right) Humpback whale vocalizations recorded off the coast of Hawaii. (right)

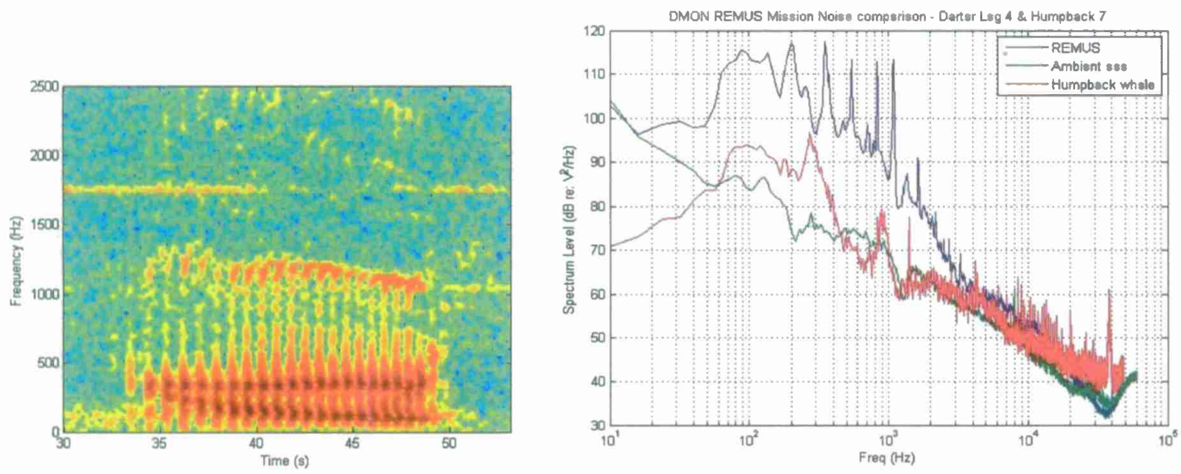


Figure 11: DMON on a WHOI REMUS
Lower frequency humpback vocalization (a) frequency spectrum (b) sound level comparison

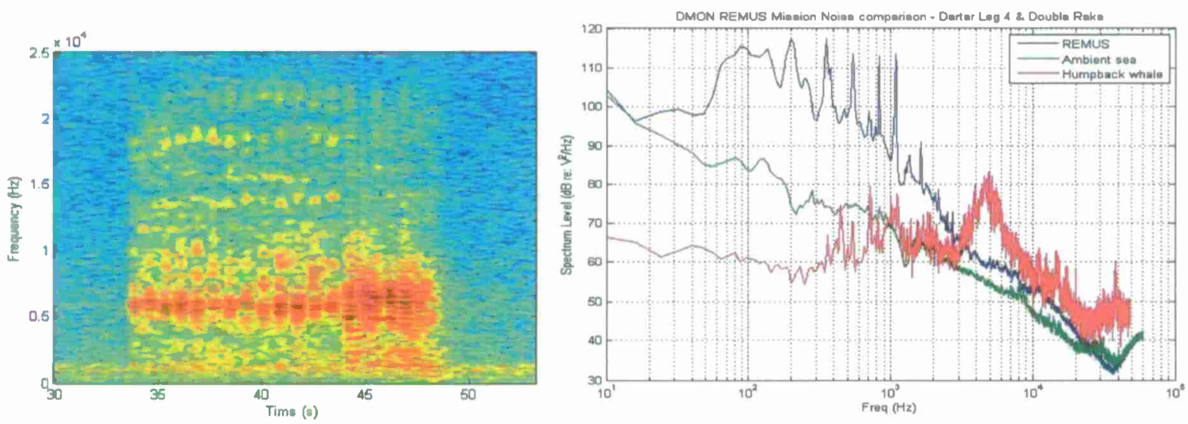


Figure 12: DMON on a WHOI REMUS
Higher frequency humpback vocalization (a) frequency spectrum (b) sound level comparison

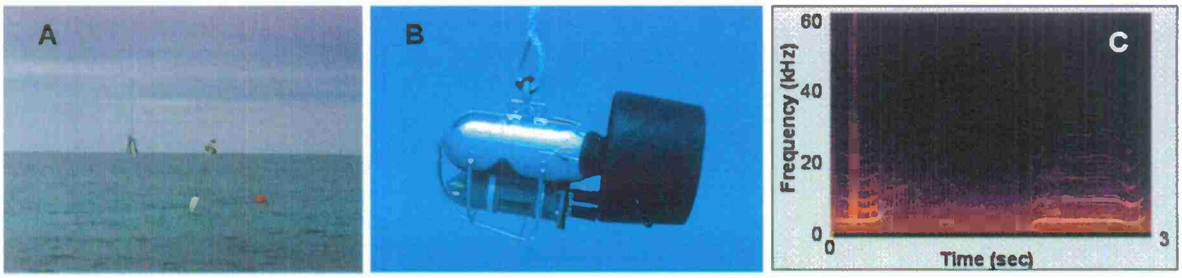
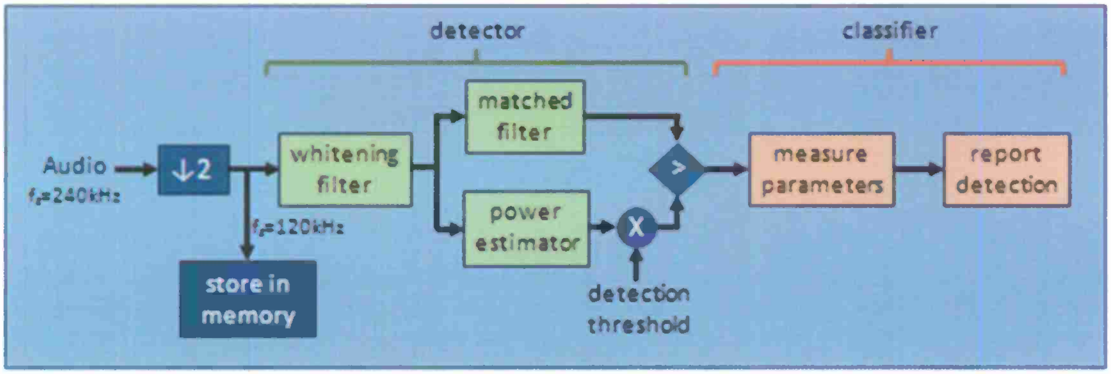


Figure 13: (A) DMON mooring at Horseshoe shoals, Nantucket Sound, site of the first windfarm in the US and one of our DMON passive acoustic monitoring sites. (B) The DMON towfish, a towfish body and fin, with a DMON attached on the underside. (C) Pilot whale whistles and clicks recorded with the DMON towfish.

DMON real-time beaked whale detector

Detector design is a pre-whitened CFAR matched filter detector with parametric classification.



User parameters:	**Value used at SCORE:**
Detection threshold	20 dB
Whitening filter	14-tap filter from Canary Islands
Matched filter	29-tap filter from Canary Islands
Classification classes	3 classes (1, 2, 3)

Figure 14: DMON Real-time Beaked Whale Detector
Block diagram of real-time detector implemented on the DMON.
(Running detection code in conjunction with continuous recording)

[title] Beta Testing of Persistent Passive Acoustic Monitoring
[awardNumber1] N00014-01-1-0381
[awardNumber2]
[awardNumberMore]
[keyWords] Animal Behavior, Animal Communications, Signal Processing, Underwater Acoustics, DMON, Beta Test, persistent monitoring, passive acoustic monitoring
[specialCat]
[pi1] Thomas Hurst
[pi2] Mark Johnson
[pi3] Mark Baumgartner
[pi4] David Fratantoni
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[bestAccomplishment] Sea-glider integration, DMON-Export licensing, DCLDE workshop attendance, ONR program review presentation, customer support for 10-15 DMON's in the field (various operations)
[comments] 2006, BSEE